Continuous and Discrete Signal

Digital Image and Sound Processing

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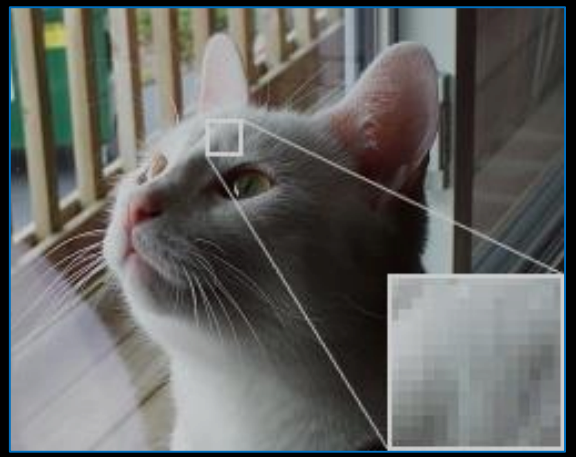
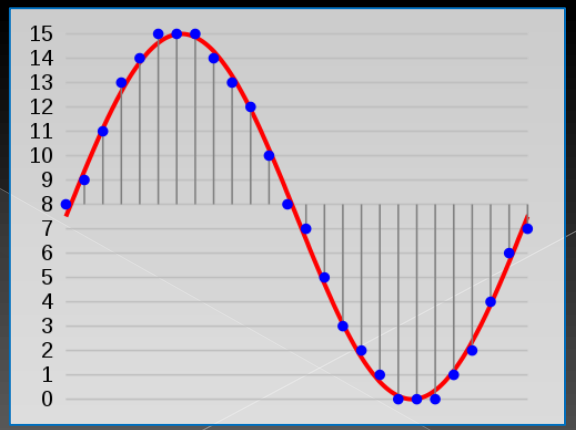
Today in the Slides

- Continuous and Discrete Signal
- Quantization
- Noise and Types of Noise
- Recording and Playing Sound
- Recording and Displaying Image

Continuous and Discrete Signal

- Before the era of digital technologies, the signal was captured in a **continuous** form
- Continuous signal has **no defined resolution**, but signal details are blurred at a certain zoom level
- Discrete signal **resolution is limited**
- **Perfect copy** of analog signal is **impossible**
- Digital storages are more **resistant** to destructive effects of the environment





[1]

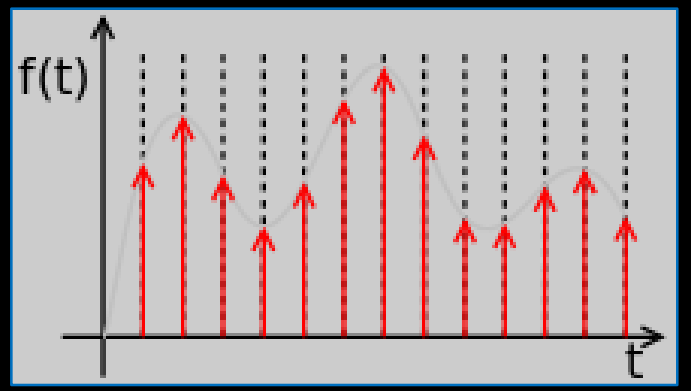
Continuous-time Signal

- Known as an **Analog** signal
- Uninterrupted form of the signal
- Can be very similar to an originally recorded sound
- „Infinite“ resolution
- Cannot be copied identically
- Storage devices and methods are prone to distortion

[2]

Discrete-time Signal

- Known as a **Digital** signal
- **Quantized** signal
  - „Stepped“ signal form
  - No inter-level values
- Limited resolution
  - Sound: time, amplitude resolution
  - Image: spatial, color depth resolution
  - Video: time, spatial, color depth resolution



[3]

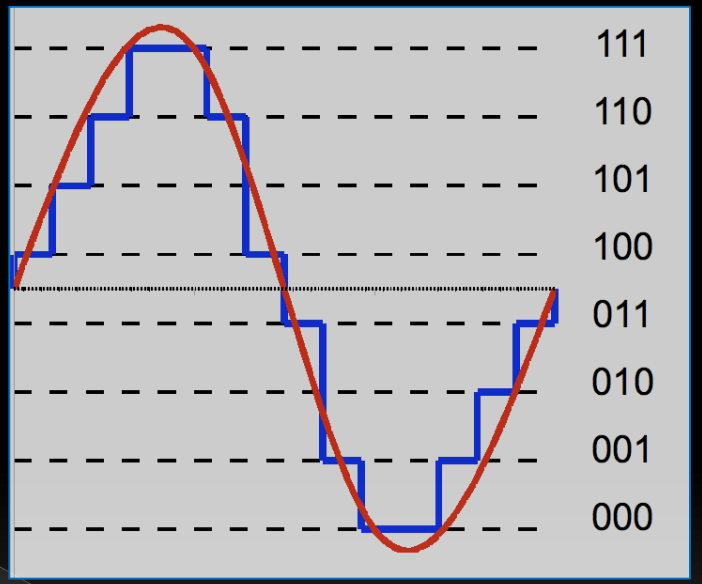
Quantization

- Used in signal discretization
- Used in lossy compression algorithms

$$Q(x) = \Delta \left\lfloor \frac{x}{\Delta} + \frac{1}{2} \right\rfloor$$

x - analog signal value

Δ - quantization step



[4]

Noise

- Noise is a disturbance (random fluctuations) of a signal
- Noise is introduced during capture, storage, transmission, processing, or conversion of a signal
- High level noise degrades essential information in a signal
- SNR (*Signal-to-Noise Ratio*) defines the ratio between signal and noise levels

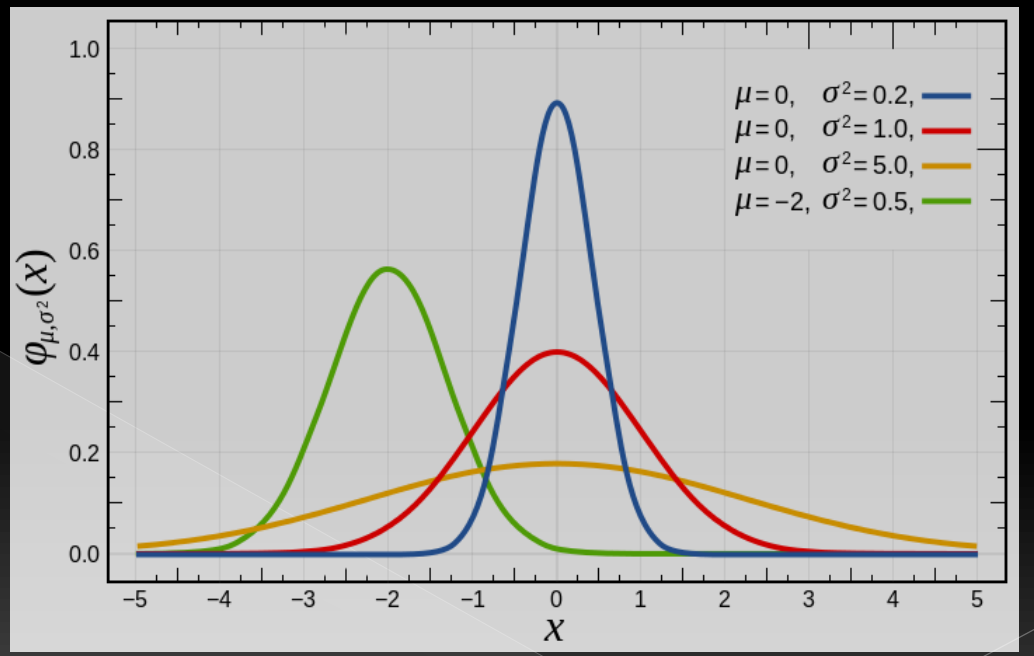
[5]

Types of Noise

- **Additive** noise
  - Gaussian noise
  - Flicker noise
  - Brownian noise
  - Cauchy noise
- **Multiplicative** noise
- **Quantization** error
- **Shot** noise
- **Transient** noise
- **Phase** noise

[5, 35]

Gaussian distribution



$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(x-\mu)^2}{2\sigma^2}}$$

μ - average

σ – standard dev.

Recording Analog Sound

- Analog sound signal is recorded by capturing air pressure variations
- Microphone converts acoustic waves to fluctuations in an electric current
- Fluctuations in an electric circuit are converted to mechanic or magnetic fluctuations in a recording device

[6, 7]

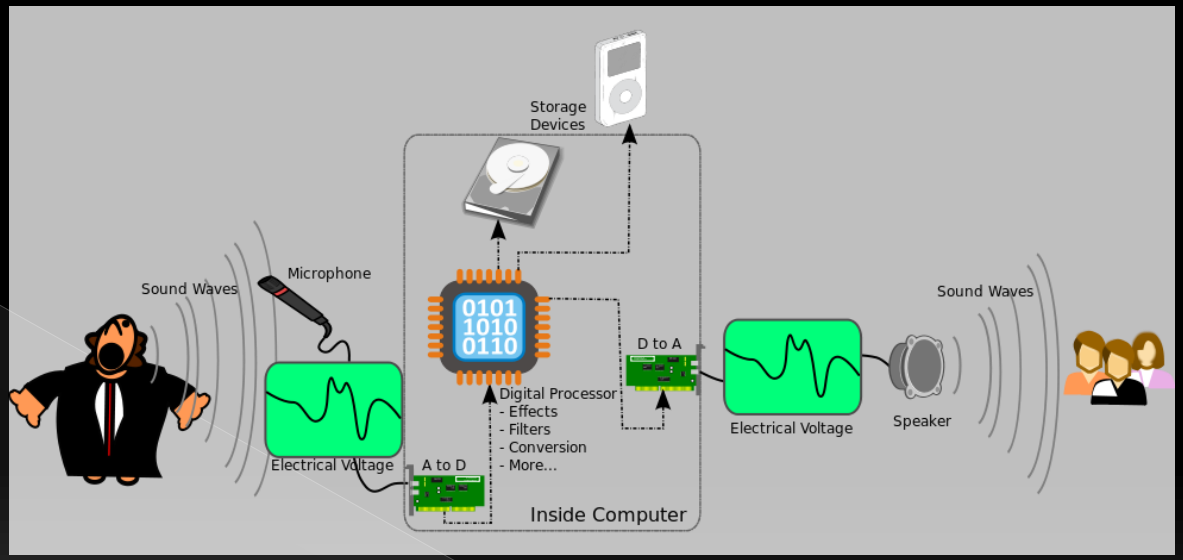
Playing Analog Sound

- Sound is generated by **converting** amplified **electric impulses to acoustic waves** in a loudspeaker

[8]

Recording and Playing Digital Sound

- ADC (Analog-Digital Converter)
- DAC (Digital-Analog Converter)
- Signal is processed before sending to a speaker



[9]

Sound Signal Characteristics

- **Bandwidth or bit-rate:**
  - Depends on physical properties of a circuit in analog systems
  - Depends on the sampling rate and device performance in digital systems
- **Sampling Rate** (time resolution)**:**
  - Indicates how often pressure levels are measured
  - Depends on the performance of a digital recording device
- **Bit-depth or Resolution** (amplitude resolution: 16, 24, 32 bits)
- **Signal-to-Noise Ratio or SNR**
- **Number of Channels**

[10, 11, 12]

Recording Analog Image

- Light stream is captured on a semi-transparent material, which reacts to the amount of light passing through it
- Image is captured on a film and later on a photographic paper or a film with a help of light-sensitive chemical elements

[13, 14, 15]

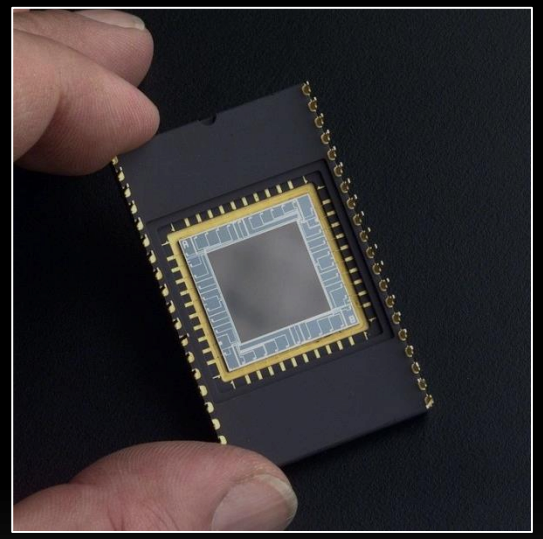
Playing Analog Image

- **Cinema**
  - Constantly changing images with the rate of 24 frames per second are merged by brain into a continuously moving picture
  - Film and movie projector
- **Television**
  - Image is captured, encoded, and stored in a magnetic videotape
  - Moving images are transmitted using radio waves or via cable and decoded in a TV set

[16, 17]

Recording Digital Image

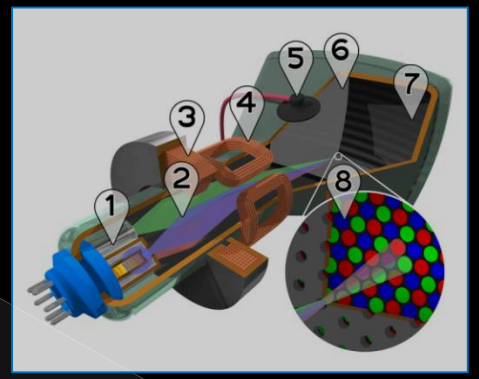
- Light is converted to voltage variations in a electric current by the help of photo-responsive elements (**CCD** – charge-coupled device)
- Digital image results from a finite number of photo-responsive elements arranged in a 2D matrix
- Each element captures the intensity of one pixel of an image

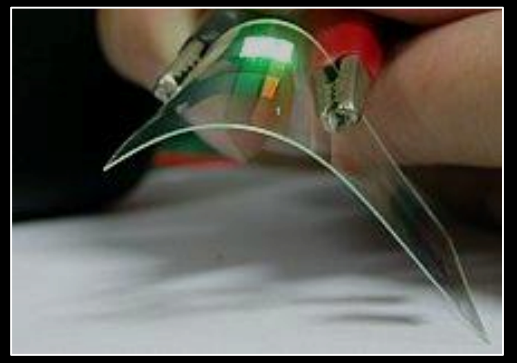


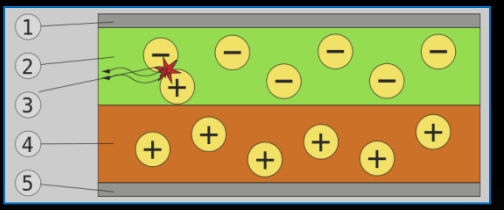
[18]

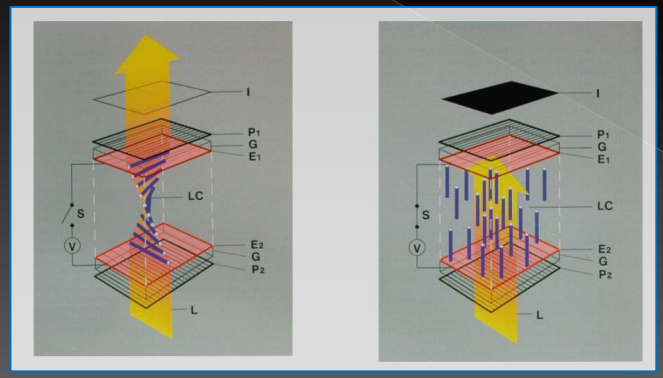
Displaying Digital Image

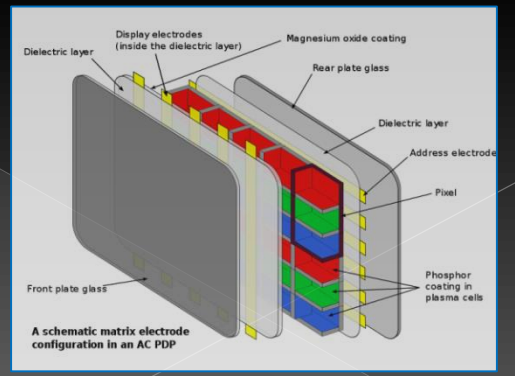
- **CRT** (Cathode-Ray Tube)
- **LCD** (Liquid Crystal Display)
  - **CCFL** (Cold Cathode Fluorescent)
  - **LED** (Light-Emitting Diode)
- **PDP** (Plasma Display Panel)
- **OLED** (Organic Light-emitting Diode)











[19, 20, 21, 22, 23, 24, 25]

Visual Signal Characteristics

- **Resolution** (spatial resolution)– the size of an image matrix (1920×1080 (HDTV), 4096×2160 (4K Digital Cinema)
- **Brightness** – the perception elicited by the **luminance** of an image
- **Contrast** – the difference in luminance or color
- **Saturation** (colorfulness) – the amount of **chrominance** in an image
- **Frame rate** (time resolution) – the number of frames per second (24 FPS, 30 FPS)
- **Color depth** – the number of bits used for the storage of one pixel
- **Color model** or **color space** – defines how a color of a pixel is encoded (RGB, HLS)

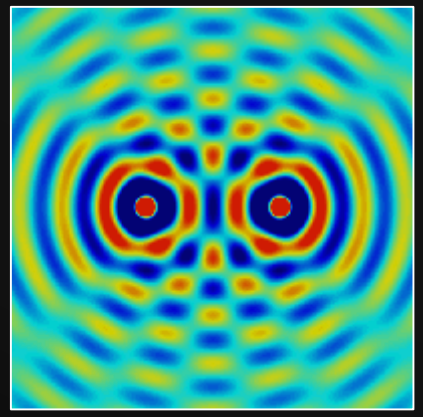
[26, 27, 28, 29, 30]

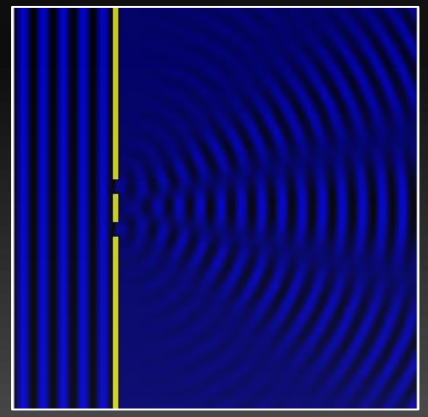
Displaying 3D Image

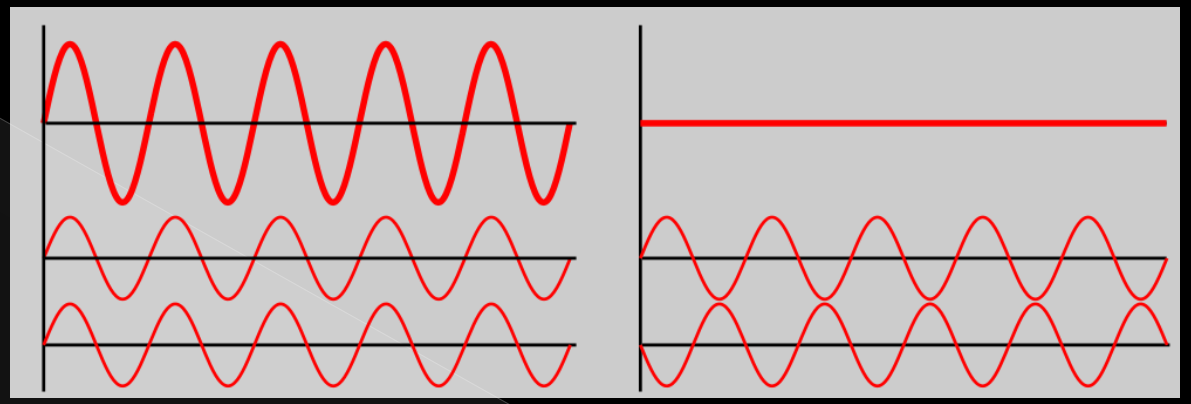
- **Stereoscopic displays**
  - Glasses are used to filter out a different image plane for each eye
  - Brain does 3D reconstruction automatically
- **Holograms**
  - Spatial images are created in a volume by using phenomenon of light diffraction and interference
  - Coherent light sources (lasers) are applied

[31]

Interference and Diffraction







- **Interference** – interaction of electromagnetic waves with similar frequencies
- **Diffraction** – ability of light to change its path when an obstacle with a size similar to a wavelength of the light is encountered

[32, 33]

Interesting Facts

- It is said that an analog sound is „warmer“ than digital because it can include subtle variations that a digital sound loses during sampling
- In audio engineering, electronics, physics, and many other fields, the color of noise refers to the power spectrum of a noise signal; there is white, pink, red, grey, blue noise
- Even though brain cannot process more than 24 frames per second, additional frames can be stored in sub-consciousness
- PDP displays loose a half of brightness after 100 000 operation hours (LCD looses as much after 30 000 – 60 000 hours); it takes 27 years if a display is running for 10 hours a day

[21, 34]

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